Outcome of radon provisions on radon levels in homes

Rasmussen, Torben Valdbjørn

Published in:
The 16th Conference of the International Society of Indoor air, Quality & Climate

Publication date:
2020

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Rasmussen, T. V. (2020). Outcome of radon provisions on radon levels in homes. In *The 16th Conference of the International Society of Indoor air, Quality & Climate: Proceeding Book* (pp. 2424-2430). [ABS-0021]

The 16th Conference of the International Society of Indoor Air Quality & Climate
ONLINE | From November 1, 2020
Paper ID ABS-0021

Outcome of radon provisions on radon levels in homes

Torben Valdbjørn Rasmussen[1,*]

[1]Department of Building Technology and Process, BUILD, Aalborg University, Copenhagen, Denmark

[*]*Corresponding email: tvr@sbi.aau.dk*

SUMMARY
The effects of the radon provisions implemented by the National Building Regulations on radon levels in homes are positive according to a survey conducted after implementing the radon provisions following council directive 2013/59/EURATOM and the recommendations by the World Health Organization. The survey presents the indoor-air radon concentration in detached and terraced single-family homes. The radon concentration was measured in 3,762 individual homes (which were completed between 1900 and 2018) during the heating season during the winters of 2015–2016, 2016–2017, and 2017–2018. Statistical calculations of the measures are the basis for the evaluation of how radon provisions, implemented as requirements in the National Building Regulations, affect the radon concentration in indoor air. The national reference level is 100 Bq/m^3, which is determined as the estimated annual mean value.

KEYWORDS
Radon, indoor air, private homes, provisions, reference level, National Building Regulations.

1 INTRODUCTION

Do the radon provisions implemented by the National Building Regulations have a positive effect on radon levels in homes? The Danish Ministry of Transport, Building and Housing raised the question after the implementation of radon provisions following council directive 2013/59/EURATOM of 5 December 2013 and the recommendations by the World Health Organization (WHO). As a national reference level, the implemented radon provisions apply to the indoor air in all buildings completed after 2010 and in workplace buildings. The WHO recommends that nation-states introduce provisions to regulate the maximum concentration of radiation in indoor air from natural sources in buildings. These recommendations are the result of the WHO's evaluation that radon is responsible for 3% to 14% of lung cancer cases, depending on the average radon exposure in different countries. Council directive 2013/59/EURATOM set basic safety standards for protection against the dangers caused by exposure to ionised radiation and obligates the EU member states to introduce a national reference level for radon in indoor air in buildings.

The health risk from exposure to ionising radiation is normally related to the concentration of radon-222 in inhaled air. Radon-222 develops from the radioactive decay of radium-226 and has a half-life of 3.8 days. This noble gas is naturally formed in the ground and penetrates through the ground slab, basement walls, and floors into buildings, and if it is not ventilated, much higher exposure can occur indoors than outdoors (Nazaroff, 1992), which is where human exposure occurs (Brunekreef and Holgate, 2002).

The WHO recommends that states introduce requirements for the maximum concentration of radiation from natural sources in indoor air. Moreover, the WHO proposes a reference level of 100 Bq/m^3 for the radon concentration in indoor air; however, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m^3. The requirements to introduce a national reference level for radon concentrations in indoor air follows council directive 2013/59/EURATOM, setting basic safety standards for protection against the dangers of exposure to ionising radiation. Exposure to an annual mean radon concentration of 300 Bq/m^3 represents approximately 10 mSv per year. It is assumed that radon is responsible for 3-14% of lung cancer incidents, depending on the average radon exposure in different countries (Zeeb and Shannoun, 2009). The impact of radon on humans show that radon is the second-largest cause of lung cancer (smoking tobacco is still the primary cause).

Indoor-air radon exposure must be taken seriously in the struggle against radon-induced lung cancer due to the large number of people who are exposed daily through indoor air in buildings (Zeeb and Shannoun, 2009). If people spend their whole lives in a building with an average radon concentration that exceeds 200 Bq/m^3, their risk of lung cancer is higher than 1%. This is far too high and is higher than acceptable levels in other contexts for a single-factor risk (Andersen et al., 1997).

Since 2010, Danish buildings must be constructed to ensure that the annual mean radon concentration in indoor air is below 100 Bq/m^3 (Danish Enterprise and Construction Authority, 2010). Buildings completed earlier are recommended to meet the same level. However, in 2018 buildings holding workspaces were included in the requirements given to new buildings constructed after 2010. Workspaces with an annual mean radon concentration in indoor air exceeding 100 Bq/m^3 must implement radon-reducing measures to reach an acceptable radon concentration. The Danish Health Authority defines the acceptable radon concentration in indoor air based on the annual mean radon concentration, the health risk of workers, and the costs to perform the necessary radon-reducing measures (The Ministry of Health, 2018). By implementing the same requirements in the Danish Building Regulations for the annual mean radon concentration in indoor air as for the requirements for workspaces, a national reference level was defined following council directive 2013/59/EURATOM and the WHO recommendations. These initiatives set the basic safety standards for protection against the dangers of exposure to ionising radiation.

The paper presents a survey in which the radon concentration in indoor air in detached and terraced single-family houses was measured in 3,762 individual houses (completed between 1900 and 2018) during the heating season during the winters of 2015–2016, 2016–2017, and 2017–2018. The results are presented as an estimated annual mean radon concentration in indoor air. Statistical calculations of the estimated annual mean radon concentration focus on how the radon provisions that were implemented as requirements in the National Building Regulations affect the indoor-air radon concentration. The national reference level is determined to be the annual mean value for indoor air and is as low as 100 Bq/m^3.

2 METHOD

Measurements were carried out in 3,762 individual homes, which were determined through an internet campaign advertised through social media, where residents were invited to participate in the radon-monitoring programme. The programme took place in individual homes during the heating season between October and April during the winters of 2015–2016, 2016–2017, and 2017–2018. The number of detectors necessary to determine the estimated annual mean radon concentration in indoor air depended on the number of rooms, size of the open space, and number of floors (Rasmussen, 2019). The detectors were distributed to each home by mail in sealed aluminium-coated envelopes and were returned after the integration period in a pre-stamped envelope. Each homeowner was asked to complete a questionnaire regarding the dates when the exposure started and ended and the type of room in which the detector was placed. The occupants were instructed regarding the placement of the detectors. The estimated annual mean radon concentration in indoor air represents the indoor-air radon concentration that occupants are exposed to on average by inhaling air indoors for one year (Rasmussen, 2019).

The estimated annual mean radon concentration in indoor air was estimated from measures carried out following a number of requirements over a period of time of less than one year (Rasmussen, 2018). The requirements include that the measures must take place in the period from 1 October to 30 April. Furthermore, the detectors must be located more than 25 cm from a wall or ceiling, 50 cm from the floor, and away from strong drafts and heat sources. Furthermore, the measurements were to be made in rooms where people spend more than four hours a day, typically in bedrooms and living rooms. In addition, the detectors were not to be placed on a tabletop of granite or put into a clay bowl. The participants were also instructed to clean and ventilate their homes as they usually would, so that representative measurements of the indoor-air radon concentration in the measurement period were obtained. The measurements followed the descriptions given in the work by Rasmussen (2018, 2019). Two detectors, at minimum, were used in the homes.

Information regarding the completion year of the houses was gathered from the Danish Building and Housing Register (Christensen, 2011), which was used for ensuring that the homes represented typical detached and terraced single-family houses in Denmark. In addition, it was ensured that the surveyed homes, as a group, reasonably reflect the number of detached and terraced single-family houses completed every year between 1900 and 2018.

In accordance with the Danish recommendations for radon measurements in private homes, the simplest assessment of radon concentrations in indoor air is based on directly integrated measurements (Rasmussen, 2018, 2019; Wraber and Rasmussen, 2011); thus, no indirect measurements (geological samples, soil gas measurements, external gamma radiation, etc.) were performed in this survey.

2.1 EQUIPMENT

The detectors were closed passive etched track detectors made from CR39 plastic film placed inside an antistatic holder. During the measurement period, alpha and its decay products cause damage to the film. By the end of the measurement period, the detectors were returned for analyses, which included etching the plastic film within the closed detector, counting the tracks, and calibrating the result. The etching took place in 20% NaOH at 90℃ for 165 min, and the tracks were counted automatically using an image scanner. The calibration exposure (normal exposure range) was 700 (60–100) $kBq{\cdot}h/m^3$, and the detector performance had a typical background of 15 $kBq{\cdot}h/m^3$. The laboratories were ISO 17025 and ISO 14001 certified and registered for the European Eco-Management and Audit Scheme. The ISO 17025 certification is an optional accredited standard that laboratories that measure radon concentration in indoor air can choose to follow. The standard describes the general requirements for the competence of testing and calibration laboratories. The measurement methods are accredited according to standards accepted in 18 European countries by the European Cooperation for Accreditation of Laboratories. Furthermore, the laboratories regularly participate in international inter-comparison tests, such as those arranged by the Health Protection Agency in the UK and Bundesamt für Strahlenschutz in Germany.

3 RESULTS

The estimated annual mean radon concentration in indoor air for every home was calculated. For homes of one level, the estimation was equal to the calculated arithmetic average of all the taken measures. If the home had more than one level, the calculated arithmetic average for each floor was calculated first, considering all measures on the individual floors. Second, the estimated annual mean radon concentration in the home was calculated as the arithmetic average for each floor (Rasmussen, 2018, 2019). A single estimated annual mean radon concentration in indoor air for each home was calculated and used for the statistical analyses.

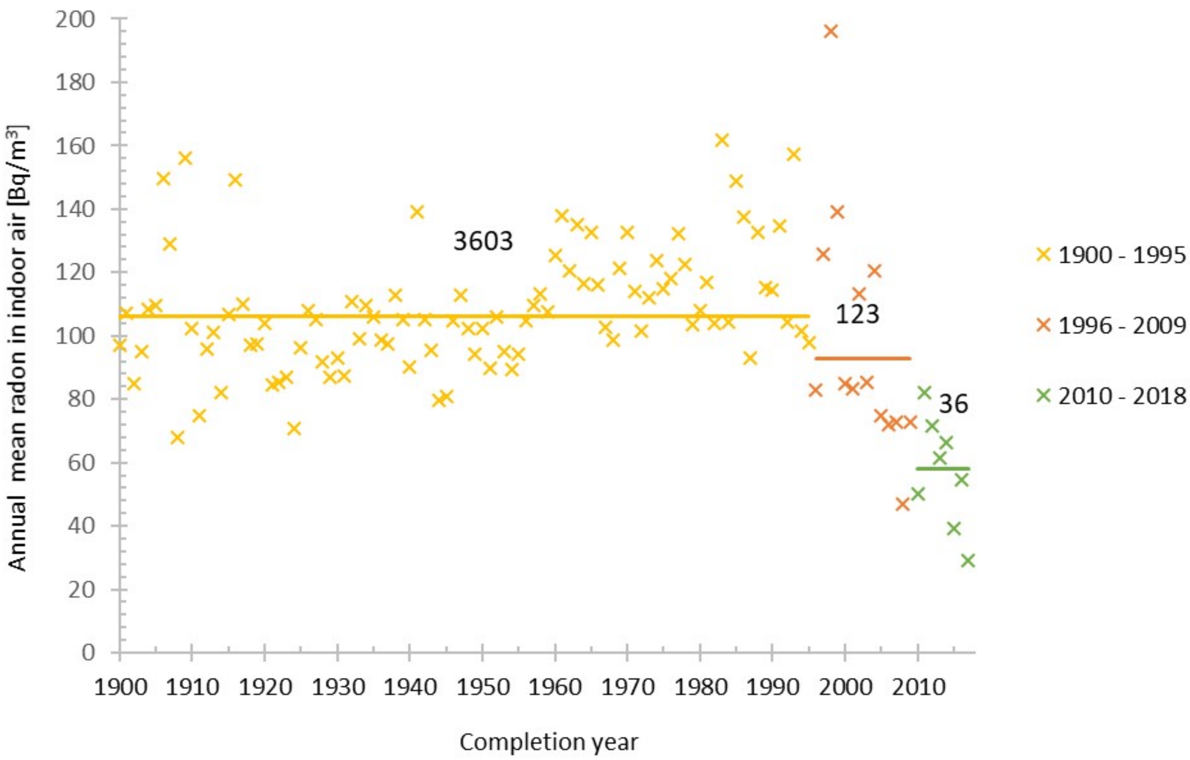

Figure 1. Average estimated annual mean radon (cross) in indoor air by completion year for houses measured during 1900–1995, 1996–2009, and 2010–2018. The straight line indicates the average for the completion-year intervals. The number of homes is given for each completion-year interval.

Figure 1 illustrates the average estimated annual mean radon in indoor air for the houses for the individual completion years, which were divided into intervals of 1900–1995, 1996–2009, and 2010–2018. For houses completed between 1900 and 1995, the average estimated annual mean radon concentration in indoor air was 106 Bq/m^3 with a minimum of 0 Bq/m^3, maximum of 804 Bq/m^3, standard deviation of 74 Bq/m^3, and median of 90 Bq/m^3. For houses completed between 1996 and 2009, the average estimated annual mean radon concentration in indoor air was 93 Bq/m^3 with a minimum of 9 Bq/m^3, maximum of 413 Bq/m^3, standard deviation of 72 Bq/m^3, and median of 74 Bq/m^3. For houses completed between 2010 and 2018, the average estimated annual mean radon concentration in indoor air was 58 Bq/m^3 with a minimum of 14 Bq/m^3, maximum of 186 Bq/m^3, standard deviation of 39 Bq/m^3, and median of 51 Bq/m^3.

Figure 2 displays the share of homes with an average estimated annual mean radon concentration in indoor air in intervals of 50 Bq/m^3, calculated by completion year for 1900–1995, 1996–2009, and 2010–2018. The share was calculated as a percentage of the number of measured homes (detached and terraced single-family houses) with the same completion-year interval.

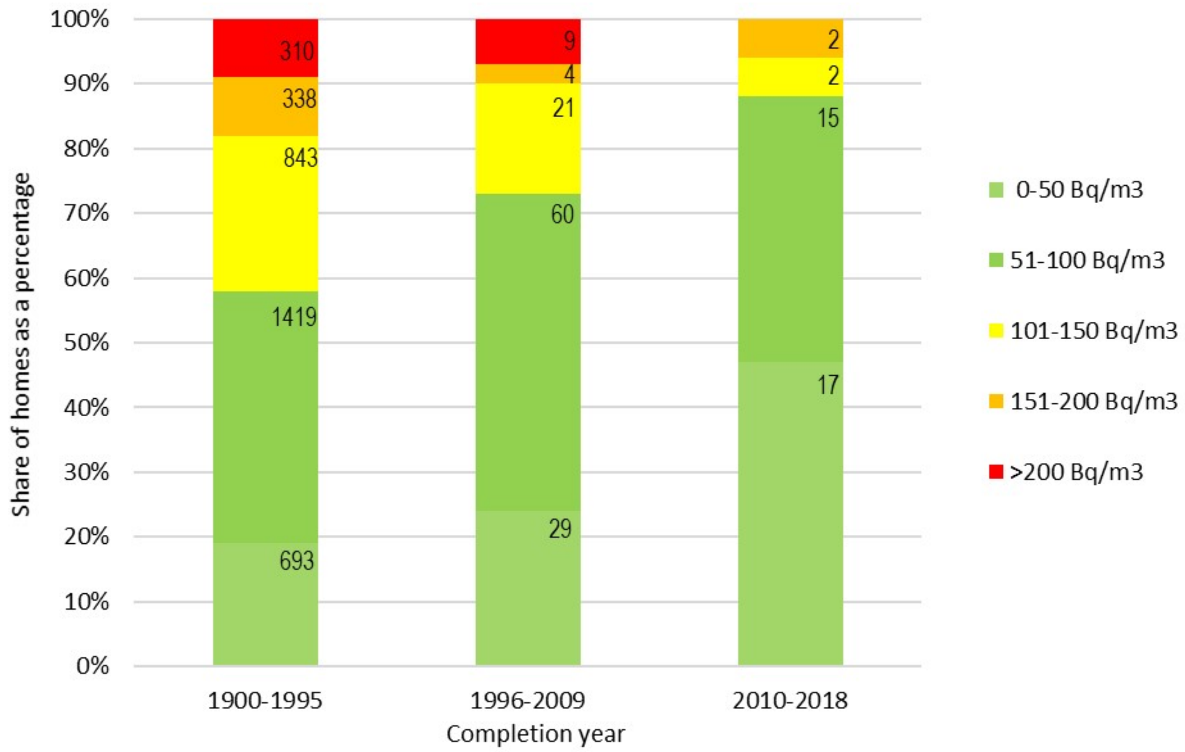

Figure 2. The share of homes with an average estimated annual mean radon concentration in indoor air calculated by completion year for 1900–1995, 1996–2009, and 2010–2018, which was calculated as a percentage of the number of homes in the same completion year interval. The estimated annual mean is shown in intervals of 50 Bq/m^3. The numbers of homes in each category are listed on the bars of the chart.

4 DISCUSSION

In 1995, the National Building Regulations implemented the first radon provisions as performance requirements, which were fully implemented by 1998. The requirements were that constructions facing the ground had to be airtight constructions (Danish Enterprise and Construction Authority, 1995). However, the requirements were implemented without a definition of what was considered acceptable airtightness. However, radon concentration in indoor air was advised not to exceed 200 Bq/m^3. In 2010, the radon provisions were followed up by implementing measurable requirements for the radon concentration in indoor air for the completed building in proper use. The requirements were that the indoor-air radon concentration of a completed building in use must not exceed 100 Bq/m^3 as an estimated annual mean (Danish Enterprise and Construction Authority, 2010).

The results show that the average estimated annual mean radon concentration in indoor air decreased from 106 Bq/m^3 for homes completed between 1900 and 1995 to 93 Bq/m^3 for homes completed between 1996 and 2009. The first radon provisions were implemented in

1995. In the same period, the standard deviation dropped from 74 to 72 Bq/m^3 and the median value dropped from 90 Bq/m^3 to 74 Bq/m^3. The improvements were not in compliance with the health improvements called for by the WHO and the European Union. However, by implementing measurable requirements as provisions in 2010, the results show that the estimated annual mean radon concentration in indoor air decreased from 93 Bq/m^3 for homes completed between 1995 and 2009 to 58 Bq/m^3 for homes completed between 2010 and 2018. In the same period, the standard deviation dropped from 72 to 39 Bq/m^3, and the median dropped from 74 Bq/m^3 to 51 Bq/m^3.

5 CONCLUSIONS

Radon provisions implemented by the National Building Regulations had a positive effect on the overall average of the estimated annual mean radon concentrations in indoor air in homes. However, to be effective, provisions must be described as clear measurable requirements and not as performance requirements.

6 ACKNOWLEDGEMENTS

This survey was supported by the Danish Association of Private Landlords of Multi-occupant Houses, the Danish Association of Non-profit Rented Homes, the Danish Ministry of Transport, Building and Housing, and Realdania, which is a philanthropic association focusing on solving challenges in Danish society in cooperation with the government, municipalities, foundations, associations, private businesses, and local, voluntary enthusiasts.

7 REFERENCES

Andersen. C.E., Bergsøe, N.C., Brendstrup, J., Damkjær, A., Gravesen, P., and Ulbak, K. 1997. *Radon-95: En undersøgelse af metoder til reduktion af radonkoncentrationen i danske enfamiliehuse (Methods to reduce radon indoors i Danish single-family terraced houses)*. In Danish. Forskningscenter Risø, Risø-R-979(DA), 108 sider, www.risoe.dk

Brunekreef, B. and Holgate, S.T. 2002. Air pollution and health. *The Lancet.* 1233–1242.

Christensen, G., 2011. The Building and Housing Register. *Scand. J. Public Health*. 106–108.

Danish Enterprise and Construction Authority, 1995. *Danish Building Regulations 1995*.

Danish Enterprise and Construction Authority. 2010. *Danish Building Regulations 2010*.

Nazaroff, W.W., 1992. Radon transport from soil to air. *Rev. Geophys*. 137–160.

Rasmussen, T.V., 2019. Determining the mean year value of radon in the indoor air. *Proceedings of the 4th Central European Symposium on Building Physics*. 2–5 September 2019. Prague, Czech.

Rasmussen, T.V., 2018. Måling af radon i bygninger (Radon measurements in buildings). In Danish. SBi-Anvisning 270. København. Denmark.

The Ministry of Health. 2018. *Announcement on ionising radiation and radiation protection (Bekendtgørelse om ioniserende stråling og strålebeskyttelse)*. In Danish. BEK no. 84 of 2/2/2018. Located 21-11-2018 at: https://www.retsinformation.dk/Forms/R0710.aspx?id=197135

Wraber, I. and Rasmussen, T.V. 2011. How to ensure low radon concentrations in indoor environments. *9th Nordic Symposium on Building Physics - NSB 2011*. Vol. 1, 105–112.

Zeeb, H. and Shannoun, F. (eds.) 2009. *WHO Handbook on indoor radon – A public health perspective*. World Health Organization. Geneva. 94 p.

The 16th Conference of the International Society of Indoor Air Quality & Climate
ONLINE | From November 1, 2020
Paper ID ABS-0283

Demystifying Regulations and Dynamic Standard Testing Methods for Formaldehyde Emissions from Wood Products

Dustin Poppendieck*, Mengyan Gong

National Institute of Standards and Technology, Maryland, USA

*Corresponding email: dustin.poppendieck@nist.gov

Keywords: Medium Density Fiberboard (MDF), Particle Board, Plywood, Emission Rate

1 Introduction

Globally, regulation of formaldehyde emissions from wood products employs a variety of measurement approaches, including extraction methods (perforation), static methods (desiccators) and dynamic methods (chambers). Given the wide variety in methods, this presentation will focus on the variety of dynamic emission tests and related regulations. For people new to dynamic emission testing, the regulations and required testing parameters may appear arbitrary. Understanding the diversity of the regulations and test methods is important when producing and specifying products for a global market.

2 Methods

This effort examined dynamic emissions testing methods and regulations in four countries: China, France, Germany, and the United States. There are five major components to national regulations of formaldehyde emission from wood products: 1) Regulatory approach; 2) Materials covered 3) Conditioning; 4) Test method; 5) Regulatory values. Although following similar logic, each of the countries addresses each of these items in a different manner. These variations could result in a product that may comply with regulations in one country but not in another country.

4 Regulatory Approach

In the United States, regulation of formaldehyde wood emissions is based upon the best available technology in 2007 to produce each type of wood product. Products were tested using historical test methods that set chamber loading ratios based upon wood usage in mobile homes in 1982. This approach results in formaldehyde emission limits that vary for each type of wood product. In contrast, Germany, France and China set a single emission limit for all wood products.

There are challenges for both approaches. The United States approach relies on dated best available technology and can lead to confusion with different wood products having emission values that vary by an order of magnitude. The single emission level approach relies upon judgement of appropriate loading ratios that are representative of real-world wood product usage. Neither approach is directly tied to health impacts.

3 Materials Covered

Products covered under formaldehyde emission testing regulations vary by nation. While particle board is commonly included, materials such as blockboard, veneer board and fiber board are explicitly or uniquely covered by in some regulations but not others.

5 Conditioning

The conditioning procedures prior to testing of the wood products vary among the testing standards. The United States primary required method (ASTM E1333) requires wood products conditioned for 7 days in 24 ℃ room with 50 % relative humidity. The Chinese standard (GB 17657 – 2013) requires a 15-day conditioning in a 23 ℃ room with an air change rate of 1 h^{-1}. Given that formaldehyde emissions can decay by up to 30 % over a week's time frame (Chen et. al. 2018), variations in conditioning and